Predictability Studies Using Adjoint Methods

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LONG-TERM GOAL

The ultimate goal of this research is to increase our understanding of the theoretical and practical limits on atmospheric predictability so as to guide the devlopment of new strategies for observing and utilizing data in an optimal manner, including defining the scientific principles for the development of an adaptive observation capability for the Navy's environmental prediction systems. In principle, this adaptive approach could revolutionize the methodology for determining initial conditions for numerical environmental prediction by coupling the data assimilation process interactively to the observation process.

OBJECTIVES

The objective of this research is to investigate the origin and growth of amplifying disturbances that profoundly influence atmospheric predictability in the 1-3 day time range using adjoint and singular vector methods. Increased understanding of rapid error growth is essential for identifying and controlling structures in forecast initial conditions that lead to large forecast errors, excercising intelligent control of our environmental observing systems, and improving methods of data assimilation. These objectives include the development and use of adjoint- and inverse-based tools to diagnose rapidly growing analysis errors in a post-time setting, which may have applications for real-time analysis corrections. The improvement of forecasts of high-impact weather, including landfalling tropical cyclones, is a major focus of this work.

APPROACH

The adjoint operator of a numerical weather prediction model is the key tool for studying atmospheric predictability on time scales of 1-3 days. The adjoint provides an efficient means of identifying regions of strong initial condition sensitivity for a particular forecast situation. The output fields from the adjoint model can be interpreted as ‘sensitivity patterns’ which identify the structures in the initial conditions that produce the maximum changes over the forecast trajectory. These patterns, and the closely related singular vectors of the tangent linear forecast model, are used to diagnose systematic errors in the current data assimilation scheme, determine optimal locations and required accuracy of in-situ and remotely sensed data, and improve estimates of key analysis error statistics.

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WORK COMPLETED

Under this initiative, NRL was a primary planner and participant in the North Pacific Experiment (NORPEX), a major inter-agency field program during Jan-Feb 1998, to investigate the impact of real-time targeted observations on 1-3 day forecasts of high-impact weather events making landfall on the U.S. west coast. Aircraft dropsonde and high-density geostationary satellite wind data were targeted in real-time using singular vector strategies developed at NRL and the data were ingested into NOGAPS operational forecasts. An extensive archive of these data has been established at NRL and their systematic evaluation and use in predictability studies formulated under this initiative are under way. NORPEX, and its participants, received significant national and international recognition for their efforts in terms of basic research critical to increasing our understanding of the practical and theoretical limits of predictability, as well as for public service for their contribution to improving operational weather forecast and public preparedness during the El Nino winter of 1997-98. In addition, we continued evaluation of the FASTEX data set (also accumulated through NRL field program participation and testing of targeted observing strategies) to investigate the origin and structure of rapidly growing initial condition errors that lead to major forecast failures.

RESULTS

Using the FASTEX and NORPEX observed data sets and the NOGAPS forward and adjoint models in well designed assimilation and forecast experiments, we have made substantial progress in demonstrating the basic scientific hypothesis that adaptive observing will provide significant improvements in numerical weather prediction skill and utility. The assimilation of dropsonde, satellite wind, and RAOB data shows that model analysis errors do in fact occur in sensitive locations identified by singular vectors and adjoint sensitivity patterns, and that reducing analysis errors in these locations can control a significant fraction of the forecast error in the verification area. Assimilation of additional observations in upstream sensitive locations identified by the leading singular vectors of the NOGAPS forecast model produced significant improvements (20-40% reductions in appropriate measures of error) in one- to two-day forecasts of extratropical cyclones during FASTEX and even greater improvements in NORPEX cases, likely due to the vastness of the Pacific data void. The forecast impacts of the additional data can be explained in terms of the analysis error projections onto the leading singular vectors.

IMPACT/APPLICATION

The results of our studies to date confirm that adjoint-based singular vectors and sensitivity information can be used effectively as a means of interpreting analysis and forecast error growth, and provide the appropriate framework for developing a real-time adaptive observing strategy. Moreover, the results hold the scientific promise that atmospheric forecasts can be improved through intelligent use and control of the observing systems, and provide important insight into the design and use of future space based sensors. The payoff of this work is the definition of new strategies for observing and utilizing data in an optimal manner for imporved forecasts of high-impact weather including lanfalling tropical cyclones. With such a capability, additional observations could be made in sensitive areas upstream from the region of interest, thereby better initializing the unstable structures that might dramatically impact the forecast.

TRANSITIONS

This work is a basic research initiative in atmospheric predictability, which has just completed its first year. Daily adjoint sensitivity calculations based on the NOGAPS 48 hour forecast errors over the Northern Hemisphere have been developed and demonstrated in real-time; these calculations continue to be run in a quasi-operational mode at FNMOC. In addition, the real-time ingestion of NORPEX adaptively targeted dropsonde and satellite wind measurements into NOGAPS during Jan-Feb 1998 and the subsequent analysis of these results have established the scientific validity of the targeted observation concept. These techniques will be ready to transition into 6.2 in the coming years.

RELATED PROJECTS

Scientific investigations will be conducted using the Navy's current NOGAPS and the newly operational Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The methodology and mathematical tools developed in support of the proposed research have direct application to ongoing NRL 6.2 programs in model development and data assimilation. The transition to operations is supported by an existing 6.4 (SPAWAR) program. ONR has initiated a 6.1 directed research initiative (DRI) on theoretical and environmental predictability; our effort is highly coordinated with these ONR initiatives. Collaborative research efforts on this task and related work have already been established with NOAA/NCEP, NOAA laboratories ETL and PMEL, NOAA's Hurricane Research Division, the National Center for Atmospheric Research, and ECMWF.

PUBLICATIONS

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